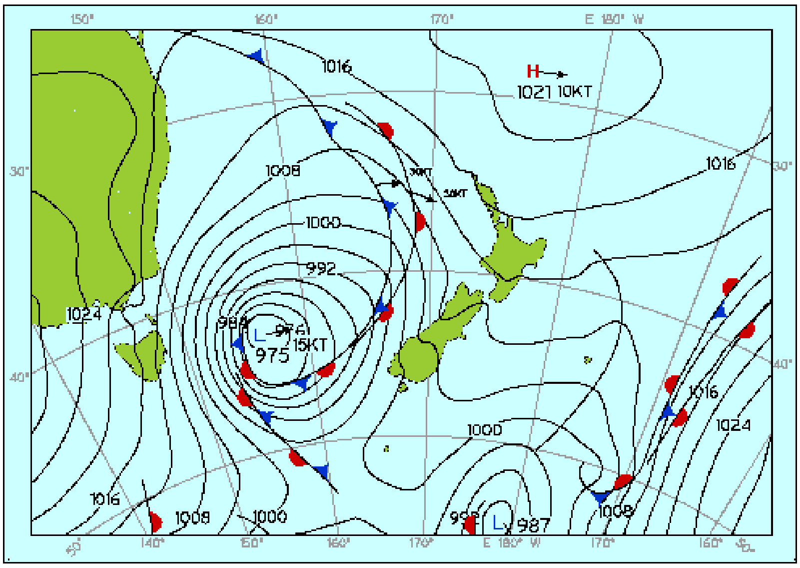
Tropical Cyclones

A tropical cyclone is a storm system characterized by a low-pressure center and numerous thunderstorms that produce strong winds and heavy rain. Tropical cyclones strengthen when water evaporated from the ocean is released as the saturated air rises, resulting in condensation of water vapor contained in the moist air. They are fueled by a different heat mechanism than other cyclonic windstorms such as nor'easters, European windstorms, and polar lows. The characteristic that separates tropical cyclones from other cyclonic systems is that at any height in the atmosphere, the center of a tropical cyclone will be warmer than its surroundings; a phenomenon called "warm core" storm systems.

Weather systems and weather maps



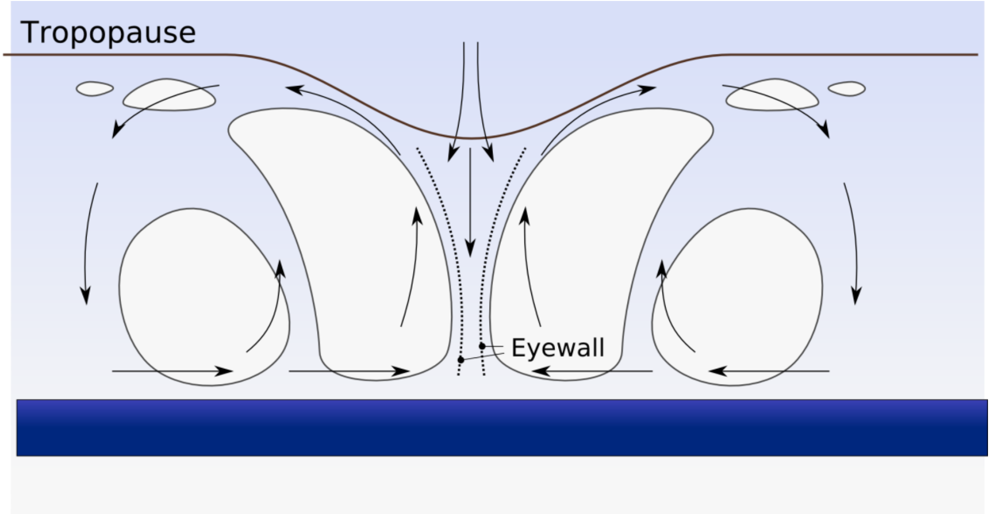
- ‘H’ means ‘high’ (= **anticyclone)**. Air pressure is above 1013. The air is descending from high, so is dry and can be cold. Clear skies or high cloud. The wind goes ANTICLOCKWISE around them.
- ‘L’ means ‘low’ (= **cyclone** or **depression**). The air pressure is below 1013. The air is rising, so it cools down and forms clouds and rain. The air goes clockwise around them.
- Wind flows parallel to the isobars (the lines on the map; lines of equal air pressure). The closer together the isobars, the stronger the wind.
- Spiky lines are cold fronts. Usually, this brings rain or storms. After it goes past, the temperature drops.
- Most weather systems move from southwest (bottom left) to northeast (top right). However, tropical cyclones move from the northwest or north.

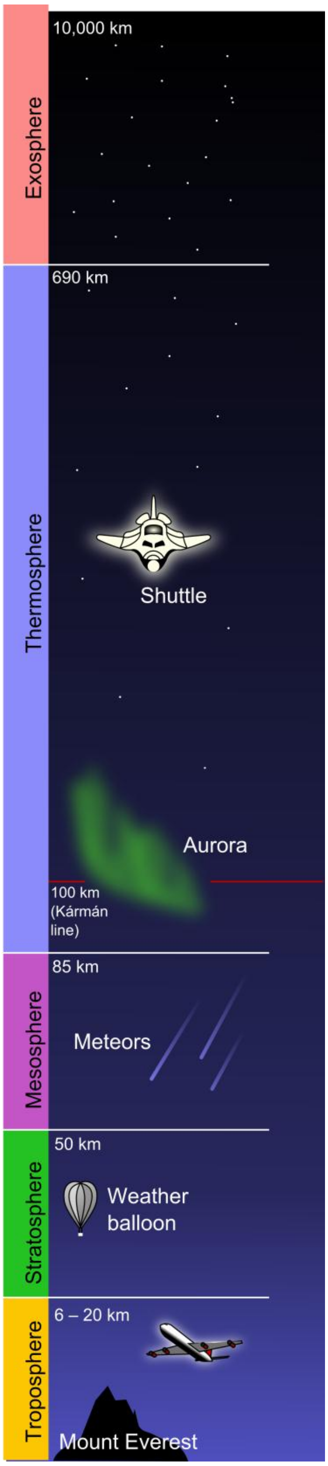
The term "tropical" refers both to the geographical origin of these systems, which usually form in tropical regions of the globe, and to their formation in maritime tropical air masses. The term "cyclone" refers to such storms' cyclonic nature, with anticlockwise wind flow in the Northern Hemisphere and **clockwise wind flow in the Southern Hemisphere**. The opposite direction of the wind flow is a result of the **Coriolis** force. Depending on its location and strength, a tropical cyclone is referred to by names such as hurricane, typhoon, tropical storm, cyclonic storm, tropical depression, and simply cyclone.

While tropical cyclones can produce extremely powerful winds and torrential rain, they are also able to produce high waves and damaging storm surge as well as spawning tornadoes. They develop over large bodies of warm water, and lose their strength if they move over land due to increased surface friction and loss of the warm ocean as an energy source. This is why coastal regions can receive significant damage from a tropical cyclone, while inland regions are relatively safe from receiving strong winds. Heavy rains, however, can produce significant flooding inland, and storm surges can produce extensive coastal flooding up to 40 kilometres (25 mi) from the coastline. Although their effects on human populations can be devastating, tropical cyclones can relieve drought conditions. They also carry heat energy away from the tropics and transport it toward temperate latitudes, which makes them an important part of the global atmospheric circulation mechanism. As a result, tropical cyclones help to maintain equilibrium in the Earth's troposphere, and to maintain a relatively stable and warm temperature worldwide.

Physical structure

All tropical cyclones are areas of low atmospheric pressure in the Earth's atmosphere. The pressures recorded at the centers of tropical cyclones are among the lowest that occur on Earth's surface at sea level. Tropical cyclones are characterized and driven by the release of large amounts of latent heat of condensation, which occurs when moist air is carried upwards and its water vapor condenses. This heat is distributed vertically around the center of the storm. Thus, at any given altitude (except close to the surface, where water temperature dictates air temperature) the environment inside the cyclone is warmer than its outer surroundings.





Eye and center

A strong tropical cyclone will harbor an area of sinking air at the center of circulation. If this area is strong enough, it can develop into a large "eye". Weather in the eye is normally calm and free of clouds, although the sea may be extremely violent.[3] The eye is normally circular in shape, and is typically 30–65 km (19–40 miles) in diameter, though eyes as small as 3 kilometres (1.9 mi) and as large as 370 kilometres (230 mi) have been observed.[4][5] Intense, mature tropical cyclones can sometimes exhibit an outward curving of the eyewall's top, making it resemble an arena football stadium; this phenomenon is thus sometimes referred to as the stadium effect. It is usually coldest in the center.

Air pressure: Air pressure is measured in hectopascals, hPa. Normal air pressure at sea level is 1013 hPa. A hectopascal is the same size as an 'American' unit called a millibar.

1000 hPa is equivalent to a mass of 10 tonnes per square metre area.

Mechanics

Tropical cyclones form when the energy released by the condensation of moisture in rising air causes a positive feedback loop over warm ocean waters. A tropical cyclone's primary energy source is the release of the heat of condensation from water vapor condensing, with solar heating being the initial source for evaporation. Therefore, a tropical cyclone can be visualized as a giant vertical heat engine supported by mechanics driven by physical forces such as the rotation and gravity of the Earth. While an initial warm core system, such as an organized thunderstorm complex, is necessary for the formation of a tropical cyclone, a large flux of energy is needed to lower atmospheric pressure more than a few millibars . The inflow of warmth and moisture from the underlying ocean surface is critical for tropical cyclone strengthening.[16] A significant amount of the inflow in the cyclone is in the lowest 1 kilometre (3,300 ft) of the atmosphere.[17]

Condensation leads to higher wind speeds, as a tiny fraction of the released energy is converted into mechanical energy; the faster winds and lower pressure associated with them in turn cause increased surface evaporation and thus even more condensation. Much of the released energy drives updrafts that increase the height of the storm clouds, speeding up condensation. This positive feedback loop, called the Wind-induced surface heat exchange, continues for as long as conditions are favorable for tropical cyclone development. Factors such as a continued lack of equilibrium in air mass distribution would also give supporting energy to the cyclone. The rotation of the Earth

causes the system to spin, an effect known as the Coriolis effect, giving it a cyclonic characteristic and affecting the trajectory of the storm. In the Northern Hemisphere, where the cyclone's wind flow is counterclockwise, the fastest winds relative to the surface of the Earth occur on the eastern side of a northward-moving storm and on the northern side of a westward-moving one; the opposite occurs in the Southern Hemisphere, where the wind flow is clockwise.

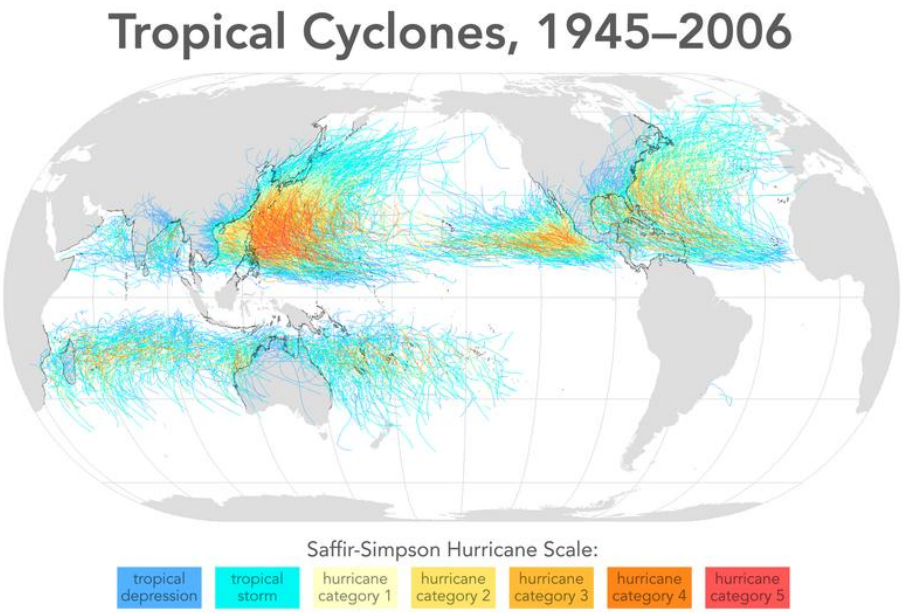
What primarily distinguishes tropical cyclones from other meteorological phenomena is deep convection as a driving force. Because convection is strongest in a tropical climate, it defines the initial domain of the tropical cyclone. By contrast, mid-latitude cyclones draw their energy mostly from pre-existing horizontal temperature gradients in the atmosphere. To continue to drive its heat engine, a tropical cyclone must remain over warm water (27°C), which provides the needed atmospheric moisture to keep the positive feedback loop running. When a tropical cyclone passes over land, it is cut off from its heat source and its strength diminishes rapidly.

Scientists estimate that a tropical cyclone releases heat energy at the rate of 50 to 200 exajoules (10^{18} J) per day, equivalent to about 1 PW (1015 watt). This rate of energy release is equivalent to 70 times the world energy consumption of humans and 200 times the worldwide electrical generating capacity, or to exploding a 10-megaton nuclear bomb every 20 minutes.

In the lower troposphere, the most obvious motion of clouds is toward the center. However tropical cyclones also develop an upper-level (high-altitude) outward flow of clouds. These originate from air that has released its moisture and is expelled at high altitude through the "chimney" of the storm engine.[15] This outflow produces high, cirrus clouds that spiral away from the center. The clouds thin as they move outwards from the center of the system and are evaporated. They may be thin enough for the sun to be visible through them. These high cirrus clouds may be the first signs of an approaching tropical cyclone.[28] As air parcels are lifted within the eye of the storm the vorticity is reduced, causing the outflow from a tropical cyclone to have anti-cyclonic motion.

Factors

The formation of tropical cyclones is the topic of extensive ongoing research and is still not fully understood.[39] While six factors appear to be generally necessary, tropical cyclones may occasionally form without meeting all of the following conditions. In most situations, water temperatures of at least 26.5 °C are needed down to a depth of at least 50 m waters of this temperature cause the overlying atmosphere to be unstable enough to sustain convection and thunderstorms. Another factor is rapid cooling with height, which allows the release of the heat of condensation that powers a tropical cyclone.[40] High humidity is needed, especially in the lower-to-mid troposphere; when there is a great deal of moisture in the atmosphere, conditions are more favorable for disturbances to develop.[40] Low amounts of wind shear are needed, as high shear is disruptive to the storm's circulation. Tropical cyclones generally need to form more than 555 km or 5 degrees of latitude away from the equator, allowing the Coriolis effect to deflect winds blowing towards the low pressure center and creating a circulation.[40] Lastly, a formative tropical cyclone needs a pre-existing system of disturbed weather, although without a circulation no cyclonic development will take place. Low-latitude and low-level westerly wind bursts associated with the Madden-Julian oscillation can create favorable conditions for tropical cyclogenesis by initiating tropical disturbances.[42]



Locations

Most tropical cyclones form in a worldwide band of thunderstorm activity called by several names: the Intertropical Front (ITF), the Intertropical Convergence Zone (ITCZ), or the monsoon trough.

Another important source of atmospheric instability is found in tropical waves, which cause about 85% of intense tropical cyclones in the Atlantic ocean, and become most of the tropical cyclones in the Eastern Pacific basin.[46][47][48]

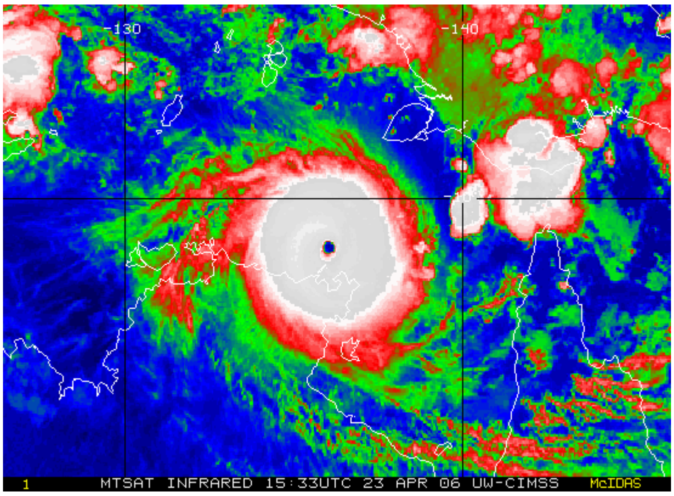
Tropical cyclones move westward when equatorward of the subtropical ridge, intensifying as they move. Most of these systems form between 10 and 30 degrees away of the equator, and 87% form no farther away than 20 degrees of latitude, north or south.[49][50] Because the Coriolis effect initiates and maintains tropical cyclone rotation, tropical cyclones rarely form or move within about 5 degrees of the equator, where the Coriolis effect is weakest.[49] However, it is possible for tropical cyclones to form within this boundary as Tropical Storm Vamei did in 2001 and Cyclone Agni in 2004.[51][52]

Movement and track

Steering winds: Although tropical cyclones are large systems generating enormous energy, their movements over the Earth's surface are controlled by large-scale winds—the streams in the Earth's atmosphere. The path of motion is referred to as a tropical cyclone's track and has been compared by Dr. Neil Frank, former director of the National Hurricane Center, to "leaves carried along by a stream".

Tropical systems, while generally located equatorward of the 20th parallel, are steered primarily westward by the east-to-west winds on the equatorward side of the subtropical ridge—a persistent high-pressure area over the world's oceans.[53] In the tropical North Atlantic and Northeast Pacific oceans, trade winds—another name for the westward-moving wind currents—steer tropical waves westward from the African coast and towards the Caribbean Sea, North America, and ultimately into the central Pacific ocean before the waves dampen out.[47] These waves are the precursors to many tropical cyclones within this region.[46] In the Indian Ocean and Western Pacific (both north and south of the equator), tropical cyclogenesis is strongly influenced by the seasonal movement of the Intertropical Convergence Zone and the monsoon trough, rather than by easterly waves.[54] Tropical cyclones can also be steered by other systems, such as other low pressure systems, high pressure systems, warm fronts, and cold fronts.

Coriolis effect



To the right is an infrared image of a powerful southern hemisphere cyclone, Monica, near peak intensity, showing clockwise rotation due to the Coriolis effect
The Earth's rotation imparts an acceleration known as the Coriolis effect, Coriolis acceleration, or colloquially, Coriolis force. This acceleration causes cyclonic systems to turn towards the poles in the absence of strong steering currents.[55] The poleward portion of a tropical cyclone contains easterly winds, and the Coriolis effect pulls them slightly more poleward. The westerly winds on the equatorward portion of the cyclone pull slightly towards the equator, but, because the Coriolis effect weakens toward the equator, the net drag on the cyclone is poleward. Thus, tropical cyclones in the Northern Hemisphere usually turn north (before being blown east), and tropical cyclones in the Southern Hemisphere usually turn south (before being blown east) when no other effects counteract the Coriolis effect.[21]

The Coriolis effect also initiates cyclonic rotation, but it is not the driving force that brings this rotation to high speeds – that force is the heat of condensation.[19]

Landfall

Officially, landfall is when a storm's center (the center of its circulation, not its edge) crosses the coastline.[58] Storm conditions may be experienced on the coast and inland hours before landfall; in fact, a tropical cyclone can launch its strongest winds over land, yet not make landfall; if this occurs, then it is said that the storm made a direct hit on the coast.[58] As a result of the narrowness of this definition, the landfall area experiences half of a land-bound storm by the time the actual landfall occurs. For emergency preparedness, actions should be timed from when a certain wind speed or intensity of rainfall will reach land, not from when landfall will occur.[58]

DissipationFactors

A tropical cyclone can cease to have tropical characteristics in several different ways. One such way is if it moves over land, thus depriving it of the warm water it needs to power itself, quickly losing strength.[60] Most strong storms lose their strength very rapidly after landfall and become disorganized areas of low pressure within a day or two, or evolve into extratropical cyclones. There is a chance a tropical cyclone could regenerate if it managed to get back over open warm water, such as with Hurricane Ivan. If it remains over mountains for even a short time, weakening will accelerate.[61] Many storm fatalities occur in mountainous terrain, as the dying storm unleashes torrential rainfall,[62] leading to deadly floods and mudslides, similar to those that happened with Hurricane Mitch in 1998.[63] In addition, dissipation can occur if a storm remains in the same area of ocean for too long, mixing the upper 60 metres (197 ft) of water, dropping sea surface temperatures more than 5 °C (9 °F).[64] Without warm surface water, the storm cannot survive.[65]

A tropical cyclone can dissipate when it moves over waters significantly below 26.5 °C (79.7 °F). This will cause the storm to lose its tropical characteristics (i.e. thunderstorms near the center and warm core) and become a remnant low pressure area, which can persist for several days. This is the main dissipation mechanism in the Northeast Pacific ocean.[66] Weakening or dissipation can occur if it experiences vertical wind shear, causing the convection and heat engine to move away from the center; this normally ceases development of a tropical cyclone.[67] In addition, its interaction with the main belt of the Westerlies, by means of merging with a nearby frontal zone, can cause tropical cyclones to evolve into extratropical cyclones. This transition can take 1–3 days.[68] Even after a tropical cyclone is said to be extratropical or dissipated, it can still have tropical storm force (or occasionally hurricane/typhoon force) winds and drop several inches of rainfall. In the Pacific ocean and Atlantic ocean, such tropical-derived cyclones of higher latitudes can be violent and may occasionally remain at hurricane or typhoon-force wind speeds when they reach the west coast of North America. These phenomena can also affect Europe, where they are known as European windstorms; Hurricane Iris's extratropical remnants are an example of such a windstorm from 1995.[69] In addition, a cyclone can merge with another area of low pressure, becoming a larger area of low pressure. This can strengthen the resultant system, although it may no longer be a tropical cyclone.[67] Studies in the 2000s have given rise to the hypothesis that large amounts of dust reduce the strength of tropical cyclones.[70]

Effects

Tropical cyclones out at sea cause large waves, heavy rain, and high winds, disrupting international shipping and, at times, causing shipwrecks.[79] Tropical cyclones stir up water, leaving a cool wake behind them, which causes the region to be less favorable for subsequent tropical cyclones.[26] On land, strong winds can damage or destroy vehicles, buildings, bridges, and other outside objects, turning loose debris into deadly flying projectiles. The storm surge, or the increase in sea level due to the cyclone, is typically the worst effect from landfalling tropical cyclones, historically resulting in 90% of tropical cyclone deaths.[80] The broad rotation of a landfalling tropical cyclone, and vertical wind shear at its periphery, spawns tornadoes. Tornadoes can also be spawned as a result of eyewall mesovortices, which persist until landfall.[81]

Over the past two centuries, tropical cyclones have been responsible for the deaths of about 1.9 million people worldwide. Large areas of standing water caused by flooding lead to infection, as well as contributing to mosquito-borne illnesses. Crowded evacuees in shelters increase the risk of disease propagation.[82] Tropical cyclones significantly interrupt infrastructure, leading to power outages, bridge destruction, and the hampering of reconstruction efforts.[82][83]

Although cyclones take an enormous toll in lives and personal property, they may be important factors in the precipitation regimes of places they impact, as they may bring much-needed precipitation to otherwise dry regions.[84] Tropical cyclones also help maintain the global heat balance by moving warm, moist tropical air to the middle latitudes and polar regions,[22] and by regulating the thermohaline circulation through upwelling.[85] The storm surge and winds of hurricanes may be destructive to human-made structures, but they also stir up the waters of coastal estuaries, which are typically important fish breeding locales. Tropical cyclone destruction spurs redevelopment, greatly increasing local property values.[86]

Observation and forecasting

Intense tropical cyclones pose a particular observation challenge, as they are a dangerous oceanic phenomenon, and weather stations, being relatively sparse, are rarely available on the site of the storm itself. In general, surface observations are available only if the storm is passing over an island or a coastal area, or if there is a nearby ship. Real-time measurements are usually taken in the periphery of the cyclone, where conditions are less catastrophic

and its true strength cannot be evaluated. For this reason, there are teams of meteorologists that move into the path of tropical cyclones to help evaluate their strength at the point of landfall.[87]

Tropical cyclones far from land are tracked by weather satellites capturing visible and infrared images from space, usually at half-hour to quarter-hour intervals. As a storm approaches land, it can be observed by land-based Doppler radar. Radar plays a crucial role around landfall by showing a storm's location and intensity every several minutes.[88]

In situ measurements, in real-time, can be taken by sending specially equipped reconnaissance flights into the cyclone. In the Atlantic basin, these flights are regularly flown by United States government hurricane hunters.[89] The aircraft used are WC-130 Hercules and WP-3D Orions, both four-engine turboprop cargo aircraft. These aircraft fly directly into the cyclone and take direct and remote-sensing measurements. The aircraft also launch GPS dropsondes inside the cyclone. These sondes measure temperature, humidity, pressure, and especially winds between flight level and the ocean's surface. A new era in hurricane observation began when a remotely piloted Aerosonde, a small drone aircraft, was flown through Tropical Storm Ophelia as it passed Virginia's Eastern Shore during the 2005 hurricane season. A similar mission was also completed successfully in the western Pacific ocean. This demonstrated a new way to probe the storms at low altitudes that human pilots seldom dare.[90]

Changes caused by El Niño-Southern Oscillation

Most tropical cyclones form on the side of the subtropical ridge closer to the equator, then move poleward past the ridge axis before recurving into the main belt of the Westerlies.[126] When the subtropical ridge position shifts due to El Niño, so will the preferred tropical cyclone tracks. Areas west of Japan and Korea tend to experience much fewer September–November tropical cyclone impacts during El Niño and neutral years. During El Niño years, the break in the subtropical ridge tends to lie near 130°E which would favor the Japanese archipelago.[127] During El Niño years, Guam's chance of a tropical cyclone impact is one-third of the long term average.[128] The tropical Atlantic ocean experiences depressed activity due to increased vertical wind shear across the region during El Niño years.[129] During La Niña years, the formation of tropical cyclones, along with the subtropical ridge position, shifts westward across the western Pacific ocean, which increases the landfall threat to China and much greater intensity in the Philippines.[127]

Global warming

The U.S. National Oceanic and Atmospheric Administration Geophysical Fluid Dynamics Laboratory performed a simulation to determine if there is a statistical trend in the frequency or strength of tropical cyclones over time. The simulation concluded "the strongest hurricanes in the present climate may be upstaged by even more intense hurricanes over the next century as the earth's climate is warmed by increasing levels of greenhouse gases in the atmosphere".[142]

In an article in Nature, meteorology professor Kerry Emanuel stated that potential hurricane destructiveness, a measure combining hurricane strength, duration, and frequency, "is highly correlated with tropical sea surface temperature, reflecting well-documented climate signals, including multidecadal oscillations in the North Atlantic and North Pacific, and global warming". Emanuel predicted "a substantial increase in hurricane-related losses in the twenty-first century".[143] In more recent work published by Emanuel (in the March 2008 issue of the Bulletin of the American Meteorological Society), he states that new climate modeling data indicates "global warming should reduce the global frequency of hurricanes."[144] According to the Houston Chronicle, the new work suggests that, even in a dramatically warming world, hurricane frequency and intensity may not substantially rise during the next two centuries.[145]

Likewise, P.J. Webster and others published an article in Science examining the "changes in tropical cyclone number, duration, and intensity" over the past 35 years, the period when satellite data has been available. Their main finding was although the number of cyclones decreased throughout the planet excluding the north Atlantic Ocean, there was a great increase in the number and proportion of very strong cyclones.[146]

1. Why are these cyclones termed ‘tropical’?
2. What water temperature is needed to sustain them, and what happens when the water is below that temperature?
3. Tropical cyclones cannot form over land. Why?
4. In which direction does a cyclone rotate in the Southern Hemisphere? Why do cyclones rotate?
5. What is the ‘eye’ of the cyclone and what causes it?
6. Where do cyclones that reach NZ originate?
7. What are the ‘weather characteristics’ of cyclones (rainfall, wind, swells)
8. Cyclones are generally downgraded from Tropical Cyclone to Storm before reaching NZ. However, they can effect NZ even before they get here. Why?